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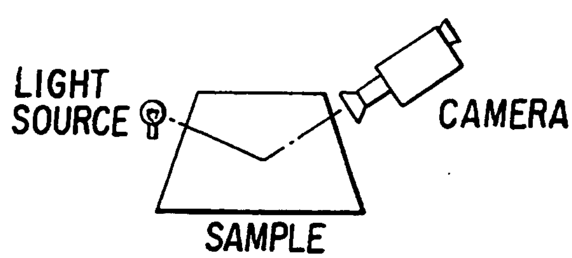
(54) Title: METHOD AND APPARATUS FOR ASSESSMENT OF SURFACE SMOOTHNESS USING REFLECTED ENERGY



(57) Abstract

A method and apparatus for assessing smoothness of a surface includes respective means for reflecting light of a uniform light source from the surface into a camera to produce a surface image, digitizing the surface image to produce a digital image comprised of pixels, determining a plurality of gradients in grey level between pairs of pixels of the digital image, and averaging the plurality of gradients to produce a surface smoothness measure.

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METHOD AND APPARATUS FOR ASSESSMENT OF SURFACE SMOOTHNESS USING REFLECTED ENERGY

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a method and apparatus for remotely assessing the smoothness of a coated surface.

2. Description of the Related Art

The automotive, appliance and other industries rely on a high quality appearance as a selling point for their products. One key attribute of appearance is the smoothness of coated surfaces, such as the painted exterior of an automobile. Smoothness includes long and short-term waviness, orange peel, and distinctness of image. Assessment of smoothness for quality control purposes currently is a labor intensive task as only human inspectors can reliably detect smoothness irregularities. An automated measurement system for surface smoothness would thus be of great benefit to these industries.

Two techniques for assessing surface smoothness have emerged. D-sight, described by Reynolds and Hageniers in Society of Manufacturing Engineers technical paper MF89-362 titled "Surface Quality Measurements on Sheet Metal Samplings", has proven to be successful in measuring long-term waviness but has not been applied to short-term waviness or orange peel. LORIA, described by Hackett and Hupp in "Laser Smooths Out Wave Measurements", Research & Development, August, 1989, has been applied to measuring orange peel and short-term waviness but is based on a technology which is more simplistic and less robust than the present invention. Basically, LORIA traces the profile of a coated surface by rastering a beam from side-to-side across the surface. The reflected laser beam is projected onto a screen, which is continuously viewed by a high resolution camera. The long-term waviness of the coated surface is obtained from deviations in the straightness of the project line while the short-term waviness is obtained from deviations in the greylevels of intensity of adjacent sampling points.

U.S. Patent No. 4,792,232 to Jobe et al. describes a method and apparatus for detecting surface deformities by reflecting a linear light pattern off of a smooth surface which is subsequently received by a light receiver. The reflected light pattern is converted by use of a computer and appropriate software into an array of pixels. The analysis of a reflected light pattern edge is performed by measuring the amount of deviation of the edge from a fitted curve and then quantifying the amount of deviation of the edge from the fitted curve.

U.S. Patent No. 4,853,777 to Hupp describes a method to determine the waviness of a smooth surface by reflecting light off of a surface and then detecting the light reflected onto a screen with a camera. The detected images are digitized to create data points. The data points are then processed to determine short term waviness and long term waviness.

U.S. Patent No. 4,863,268 to Clarke et al. is an improvement over U.S. Patent No. 4,629,319. The method described comprises the steps of illuminating the surface to be analyzed to reflect light onto a retro-reflective surface and collecting the reflection of the retro-reflected light off of the surface. The method also includes the step of comparing gray level images of the surface to a plurality of stored images of different samples having varying levels of distortion severity. The patent to Clarke et al requires a retro-reflector surface.

U.S. Patent No. 4,872,757 to Cormack et al. describes a method to analyze the surface smoothness of an object by detecting the shadow image of an edge of a convex object illuminated by uniformly converged white light, generating pixel outputs for determining vertical location on the edge, moving the object to provide plural edges, and averaging pixel distance measurements to produce a surface profile display.

SUMMARY OF THE INVENTION

It is an object of the present invention to overcome limitations in the prior art. It is yet another

object of the present invention to obtain higher resolution per sample surface area, to quantitatively assess smoothness in metrics comparable to industry standards, to obtain smoothness measures at speeds compatible with manufacturing production line speeds, to obtain smoothness measures from compact equipment simple in design, and to obtain smoothness measures in equipment compatible with color measurement.

These and other objects are achieved in an apparatus to assess smoothness of a surface which includes a uniform light source disposed at an angle of incidence with respect to the surface, a camera disposed at an angle of reflection with respect to the surface so as to produce a surface image, a device for digitizing the surface image to produce a digital image comprised of pixels characterized by greylevel, a gradient determining device for determining gradients between pairs of pixels of the digital image, and an averaging device for averaging the plurality of gradients to produce a surface smoothness measure, wherein the angle of incidence is equal to the angle of reflection and the angle of incidence is about 45°.

These and other objects are achieved by a method for assessing smoothness of a surface including the steps of reflecting light of a uniform light source from the surface into a camera to produce a surface image, digitizing the surface image to produce a digital image comprised of pixels, determining a plurality of gradients in greylevel between pairs of pixels of the digital image, and averaging the plurality of gradients to produce a surface smoothness measure.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described in detail in the following description of the preferred embodiments with reference to the following figures wherein:

Figure 1A is a schematic showing the setup of the present invention;

Figure 1B is a schematic showing the setup of a known technique (LORIA);

Figure 1C is a schematic showing the setup of a known technique (D-Sight);

Figure 2A is a digitized image of orange-peel;

Figure 2B is a graph of two profile traces for two coated specimens exhibiting orange-peel;

Figure 3A is a graph illustrating a comparison between the surface smoothness value obtained by the present invention and industry standard orange peel panel designations; and

Figure 3B is a graph illustrating a comparison between the surface smoothness value obtained by the present invention and profilometer measurements.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the present invention (refer to Fig. 1A) a coated surface is placed under a high resolution camera at an angle of approximately 45 degrees. A uniform light source is aimed at the coated surface at an angle of 45 degrees with respect to the sample and 90 degrees with respect to a camera. Thus, light emitted from the uniform light source and specularly reflected by the sample will be captured by the camera. This captured light is subsequently digitized by an image processing system to create the surface image of pixels characterized by greylevel.

Figure 2A is a digitized image depicting orange-peel for a coated panel having R_a=0.75 as measured by a profilometer. Figure 2B is a graph of greylevel versus position for two orange-peel samples. R_a is an industry recognized measure of average roughness determined as the average height of roughness component irregularities from a mean line measured with a sampling trace of length L. The figure shows profile traces for two coated specimens exhibiting orange-peel where specimen 1 was judged to have the more severe orange peel. Thus, the surface image so digitized is shown to be approximately the equivalent of what a human observer perceives when the human observer views the coated surface.

The camera focal distance and image magnification may be adjusted so that any size area may be analyzed and the resolution of the image may also be increased by selecting a camera with a higher resolution detector array. In Figure 1A a camera with a 512 x 250 pixel detector array was used in imaging a one square inch area of the sample area of the coating providing an image resolution of 0.004 inches. Obviously if the density of the detector array was to be increased to 1024 x 1024 or 2048 x 2048, then the image resolution would be approximately 0.001 or 0.0005 inches, respectively.

After digitization, the image is transformed by processes to quantify the surface smoothness of the sample. Such techniques as autocorrelated measures and fractal dimensions are used to provide a numerical value for surface smoothness.

When the surface to be analyzed is viewed with the video camera, a digital image is obtained and stored. The digital image preferably consists of a two-dimensional array of pixels each assigned a greylevel between 0 and a maximum integer value, 0 corresponding to dark black while the maximum integer value corresponds to bright white. The maximum integer value depends on the resolution of the image digitization process. An eight bit digitizer will result in grey levels between 0 and 255 while a 10 bit digitizer will result in grey levels between 0 and 1023. Because of the physical setup of the camera and lighting, this digital image is a mapping of the physical surface being viewed. To assess orange peel, the digital image is analyzed to determine the local slope given by the average change in greylevel per n pixel distance (n is typically 1 to 5). Thus, if GR(i,j) represents the greylevel of the pixel at location (i,j), the average slopes in the x and y directions for a distance of one pixel for an N by M image could be determined from:

$$Slope(\Delta x=1) = \frac{\sum_{i=1}^{N-1}\sum_{j=1}^{M} abs[GR(i+1,j)-GR(i,j)]}{(N-1)*M}$$

$$Slope(\Delta y=1) = \frac{\sum_{i=1}^{N}\sum_{j=1}^{M-1} abs[GR(i,j+1)-GR(i,j)]}{N*(M-1)}$$

The magnitudes of these slope values have been found to correlate quite well with metrological measurements of the slope (made with a stylus profilometer instrument) for a standard set of orange peel panels used throughout the automotive industry.

It will be appreciated by persons skilled in the art that any number of other complex descriptors of surface smoothness may be used to obtain desired measures of surface smoothness.

The ability of the present invention to discriminate between different levels of orange peel can be ascertained by comparing quantitative smoothness evaluations with the qualitative measurements of smoothness currently used by the automotive industry, specifically Advanced Coating Technologies, Inc. (ACT) set of orange peel standards (formerly called the DuPont Standards). The ACT standards consist of a set of ten coated steel panels painted to decreasing levels of orange peel; that is, the ACT standard number one has the high degree of orange peel while the coated surface of ACT standard number ten has a mirror finish. The ten ACT orange peel standards were quantified by the present invention and these values were then plotted against the corresponding standard number in Figure 3A. From Figure 3A, excellent agreement exists between the value produced by the present invention and the orange peel value assigned to the standards. In Figure 3B, the orange peel values determined by the present invention are plotted against a measure of the slope of roughness as determined by a stylus profilometer for the same panels used in Figure 3A.

From Figure 3B, it is seen that excellent agreement exists between these two measures of roughness.

It will be appreciated by persons skilled in the art that the present invention's capabilities could be greatly increased through the adoption of current color imaging technology. Specifically, since the present invention views an area of the coated surface, a color camera could be utilized to concurrently assess both surface smoothness and color. This enhancement would provide the capability to make two key quality control measurements with the same set of equipment.

Having thus described the preferred embodiments, it will be appreciated by persons skilled in the art that the described apparatus assesses smoothness by imaging the energy reflected from the surface. By proper placement of the camera and proper selection of the lighting conditions, an image of the surface structure corresponding to what the consumer perceives can be obtained. The image is then analyzed using fractal and autocorrelative analysis to quantify the smoothness. The evaluation system (lights and camera) is compact enough to be mounted on a robotic arm programmed to follow the complex contours of an item such as an automobile as it moves along a production assembly line. Thus, the surface smoothness, which is critical to industries such as the automobile and appliance industries where the product appearance is crucial to consumer acceptance of a product, may be quantitatively assessed by a compact and simple in design apparatus.

Having described the preferred embodiments of a novel method for remotely assessing the smoothness of a coated surface, it is noted that modifications and variations can be made by persons skilled in the art in view of the above teachings. It is therefore to be understood that changes may be made in the particular embodiments of the invention disclosed which are within the scope and spirit of the invention as defined by the appended claims.

Having thus described the invention with the details and particularity required by the patent laws,

what is claimed and desired protected by the letters patent is set forth in the following claims.

WHAT IS CLAIMED IS:

1. A method for assessing smoothness of a surface comprising the steps of:

reflecting light of a uniform light source from the surface into a camera to produce a surface image;

digitizing the surface image to produce a digital image comprised of pixels;

determining a plurality of gradients in a greylevel between pairs of pixels of the digital image; and

averaging the plurality of gradients to produce a surface smoothness measure.

2. The method of claim 1, wherein the uniform light source is disposed at an angle of incidence with respect to the surface;

the camera is disposed at an angle of reflection with respect to the surface;

the angle of incidence equals the angle of reflection; and

a projection of the camera and a projection of the uniform light source onto a plane containing the surface are collinear with a point of reflection.

3. The method of claim 2, wherein the angle of incidence is 45 degrees.

4. An apparatus to assess smoothness of a surface comprising:

a uniform light source disposed at an angle of incidence with respect to the surface;

a camera disposed at an angle of reflection with respect to the surface so as to produce a surface image;

means for digitizing the surface image to produce a digital image comprised of pixels;

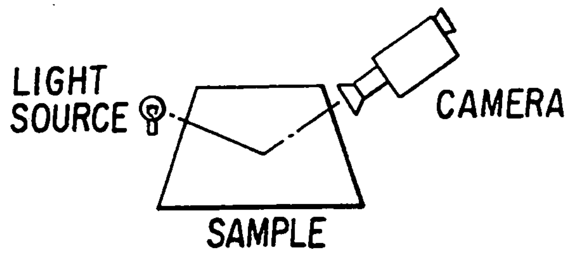
means for determining a plurality of gradients in greylevel between pairs of pixels of the digital image; and

means for averaging the plurality of gradients to produce a surface smoothness measure.

5. The apparatus of claim 4, wherein the angle of incidence is equal to the angle of reflection.

6. The apparatus of claim 4, wherein the angle of incidence is 45 degrees.

FIG. 1A



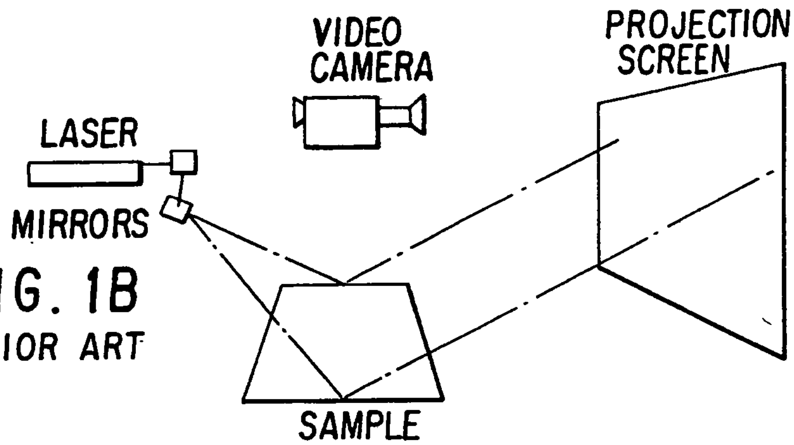


FIG. 1B
PRIOR ART

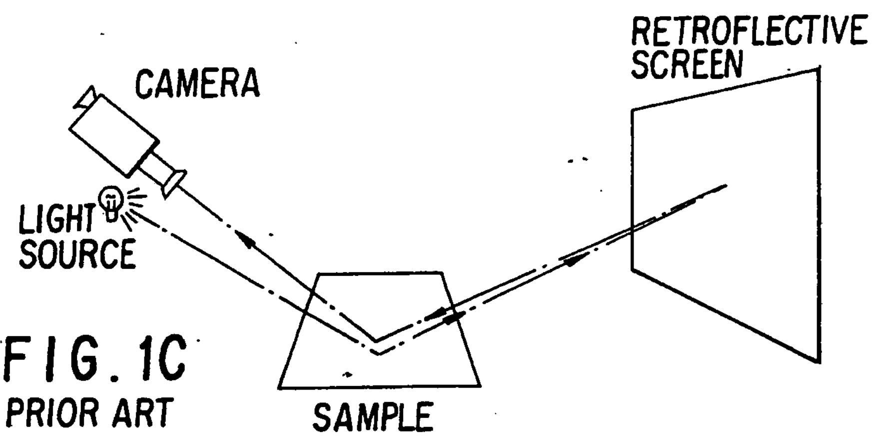
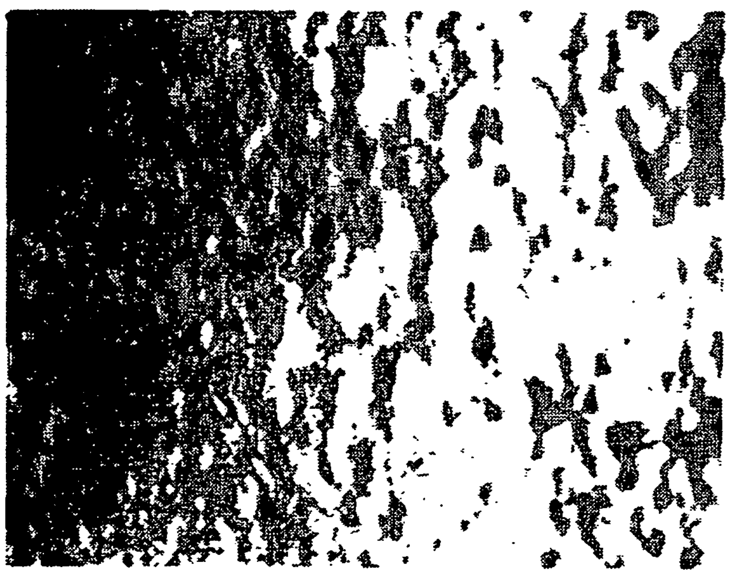


FIG. 1C
PRIOR ART

FIG. 2A



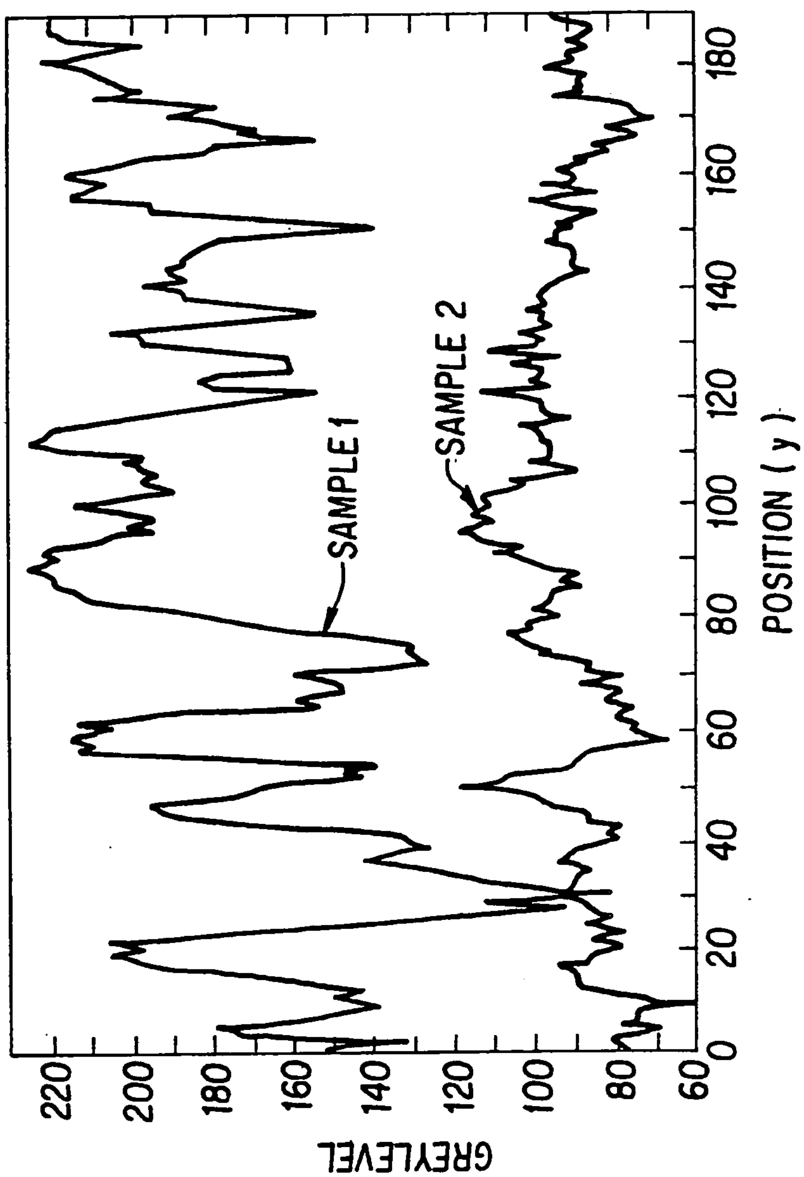

GREYLEVEL
220
200
180
160
140
120
100
80
60
POSITION (y)
0
20
40
60
80
100
120
140
160
180
SAMPLE 1
SAMPLE 2

FIG. 2B

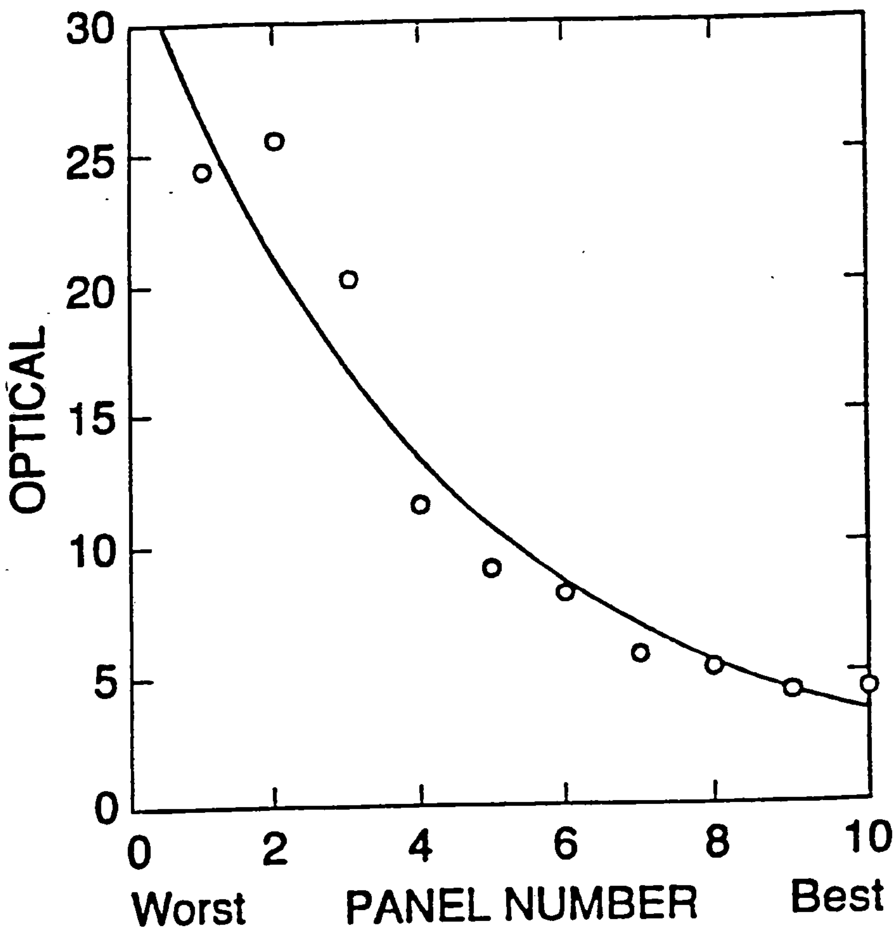


FIG. 3A

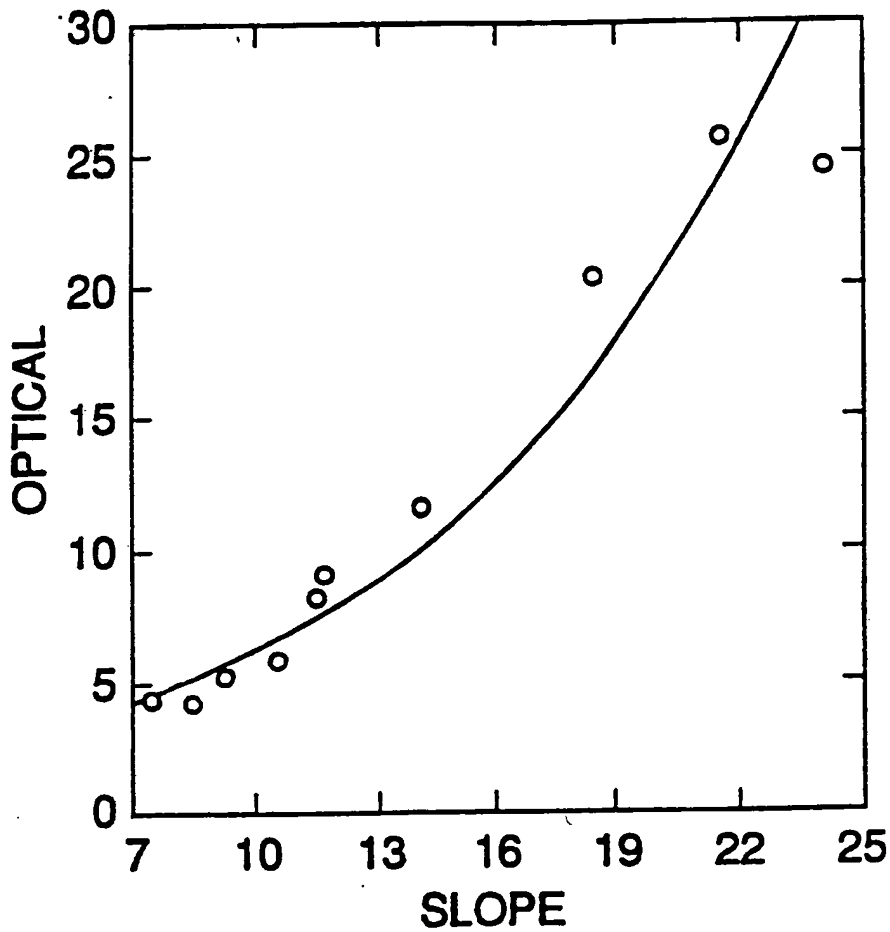


FIG. 3B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US92/11151

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :H04N 7/18
US CL :358/106, 356/371, 356/376
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 358/107, 356/366

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y,P	US,A, 5,078,496 (Parker et al) 07 January 1992 col. 3, lines 66 to col. 6, line 57.	1-6
Y	US,A, 4,974,261 (Nakahara et al) 27 November 1990 col. 6, lines 26-62.	1-6
Y	US,A, 3,971,956 (Jakeman et al.) 27 July 1976 col. 6, lines 16-21.	1-6
Y	EP,A, 374,977 (Fiatauto S.P.A.) 27 June 1990 col. 3, lines 31-33.	3,6
Y	US,A, 4,853,777 (Hupp) 01 August 1989 col. 6, lines 27-31.	1-6

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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10 FEBRUARY 1993	21 APR 1993

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y,P	US,A, 5,125,746 (Lipshita) 30 June 1992 col. 5, line 20 to col. 5, line 29.	5-6
A	US,A, 5,016,099 (Bongardt et al.) 14 May 1991.	1-6
A	US,A, 4,872,757 (Cormack et al.) 10 October 1989.	1-6
A	US,A4863,268 (Clarke et al) 05 September 1989.	1-6
A	US,A, 4,792,232 (Jobe et al.) 20 December 1988.	1-6
A	US,A, 3,922,093 (Dandliker et al) 25 November 1975.	1-6